MODULE 12
FOSSIL FUELS AND CLIMATE CHANGE

STUDY GUIDE

In this Module we investigate a topic of everyday concern, namely the world's climate and whether it is being changed by the burning of fossil fuels such as coal, gas and oil.

To do this you will *apply* a number of the skills and concepts from earlier Modules, and examine some of the underlying scientific processes involved. You will need to carry out straightforward calculations of the amounts of carbon dioxide (CO_2) being added to the atmosphere today as a result of the burning of these fossil fuels.

Ideas from previous Modules that you will encounter here include chemical equations (Modules 5/6), and energy and the burning of fuels (Module 8). Calculations involving large numbers are similar to those described in Module 4. The Earth's carbon cycle, which is introduced in this Module, is similar to the nitrogen and water cycles (Modules 5/6). The carbon cycle involves the processes of photosynthesis and respiration (Module 7), as well as combustion.

You will need a calculator, a rubber and a soft pencil for plotting data on graphs. Using graphs you will work out the rate at which one feature is changing compared to another, as you did in Modules 7 and 8.

A new skill introduced here is that of producing a model of the processes going on in nature, and then doing calculations to test whether observations agree with the model. This has some similarities to the physical model of the Earth that you met in Module 9, but here we model chemical *processes*.

This Module should take about 4/5 hours, so if you study it in the same week as Module 11 you should expect to spend a total study time of about 12 hours.

1 INTRODUCTION: BURNING FOSSIL FUELS

The issue with which this Module is concerned can be simply put. We know that by burning fossil fuels which contain carbon compounds, we add a lot of carbon dioxide (CO_2) to the atmosphere each year. We also know that CO_2 is a gas which will tend to make the Earth warmer by 'trapping' heat from the Sun. This is called the '**greenhouse effect**'. But the crucial question is: are we adding sufficient quantities of CO_2 to the atmosphere to cause the Earth's climate to change significantly, giving rise to '**global warming**'?

This is a complex question and it has important implications for humanity far beyond the realms of science. But the concepts of science, together with scientific measurements, can take us a good way towards answering the question posed in the previous paragraph. Science can, moreover, show how further work might lead to more definite conclusions.

Much of the interest and skill of scientific work is in separating what is known (fact), from what is uncertain (speculation). Science can help us to choose sensibly between possible alternative ideas (or **models**) based on these facts. For example, you may well have heard two quite different views expressed about climate change:

'The Earth's climate is now being changed so fast by human activities that global warming will have a catastrophic effect for humanity in the next few years.'

Or, alternatively:

'The Earth's atmosphere is so vast that human activities will never have any effect on the Earth's climate.'

If one of these statements is completely correct, the other one must be wrong. The truth may, of course, lie somewhere in between. So, can we begin to see where the truth lies?

The essence of a good scientist is someone who is always questioning and is ready to consider new ideas, especially if they explain some event not well understood before. When scientists speculate about what they cannot yet prove they may disagree, and when it comes to predicting what may happen in the future they may make mistakes like anyone else.

When investigating a complex topic such as climate change, one approach is to break the problem down into simpler questions. Having found answers to these simple questions, the next step is to put the answers together to see if we get a sensible answer to the original question. So we are going to split the question in the first paragraph of this Section into five parts as follows:

(i)   What is the chemical composition of fossil fuels? (This is dealt with in Section 2.)

(ii) How much CO_2 is produced when we burn different types of fossil fuels? (This is covered in Section 3.)

(iii) How has the quantity of CO_2 in the atmosphere changed over recent years? (This is discussed in Sections 4–6.)

(iv) Are the amounts of fossil fuels we are burning today enough to cause a significant increase in CO_2 in the Earth's atmosphere? (This is investigated in Sections 7 and 8.)

(v)   What future effects might current levels of atmospheric CO_2 have on the Earth's climate? (This is investigated in Sections 9 and 10.)

For the first three questions above we can get accurate answers, but for questions (iv) and (v), there is still considerable uncertainty. By following the argument through step by step, you should be more aware of just what these uncertainties are. When trying to understand the complexities of the natural world, a knowledge of basic scientific principles, such as that required to answer the five questions above, is often not enough to predict with absolute certainty what will happen in the future.

2 COMPOSITION OF FOSSIL FUELS

This Section looks at what **fossil fuels** are, their chemical composition and how they were formed. The main fossil fuels are coal, natural gas and oil. All of these are found in rocks, and were formed millions of years ago from the remains of living materials.

Plants are made up largely of carbon compounds and water. Coal formed when land plants, mainly huge ferns and trees, died and fell into shallow swampy pools. Before rotting away, they were covered by sediments consisting of sands and clays. Very occasionally whole trees, still in their growing position, are found preserved in the rocks, as shown in Figure 1a. But more commonly, detached leaves and branches are found preserved as fossils, as shown in Figure 1b.

FIGURE 1 (a) Members of the British Association for the Advancement of Science inspect a fossil tree trunk in a Manchester coal mine. (1842, the days when geologists in top hats wore white kid gloves to work!)

The original woody plant materials were compressed as the sediments in which they were encased became buried deep in the Earth's crust to eventually become sedimentary rocks (Module 3). Changes took place to the plant material—such as the loss of water—leading to enrichment in the element carbon and eventually the formation of coal seams. Later these layers of sedimentary rock, with their seams of coal, returned to positions closer to the Earth's surface due to the removal of overlying rocks by erosion. The most important coal deposits in Great Britain were formed about 300 million years ago during the Carboniferous Period (Module 3, Figure 6).

Oil and natural gas, the remains of minute animals and plants which once lived in the sea, formed in a similar manner to coal. When they died their bodies accumulated on the ocean floor and were covered by layers of sediment. Like coal, they have undergone chemical changes while buried deep in the Earth, but in this case they formed oil and gas. Both of these materials are fluids and have percolated up through the Earth's crust to accumulate near the surface. The most important oil and gas deposits in the North Sea were formed from organisms which lived about 150 million years ago.

Coal, oil and natural gas are made up of a variety of organic chemical compounds, whose main chemical elements are shown in Table 1.

FIGURE 1 (b) Fossil plant leaves (×1) preserved as a film of carbon in the rocks at the top of a seam of coal.

TABLE 1 Composition of typical fossil fuels (% by mass of the major elements).

Element	coal	gas	oil
carbon	85	80	85
hydrogen	5	20	12
others, (mostly oxygen, nitrogen, sulphur)			
totals			

☐   Work out how much of the 'other elements' are present in these fuels by completing the last two lines of Table 1.

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■ The 'totals' along the bottom row must all be 100 because that is what 100 percent means. The 'others' row is the difference between the total of the top two rows and 100. The figures are: coal = 10, gas = 0, oil = 3.

You can see from this answer that gas contains very little in the way of 'other elements'. Coal and oil often have considerable quantities of sulphur, which, when burnt produces harmful sulphuric acid. Sulphuric acid is one of the chief components of 'acid rain'.

When any of these fuels are burned, whether in a power station, a domestic fire, or a car's engine, they undergo **combustion;** a chemical reaction, which results in the fuel combining with oxygen to produce (mostly) carbon dioxide and water and, of course, heat. The chemistry of this was discussed in Module 7. You also learned about the chemical energy of fuels in Module 8, especially in Figure 8, the toy train model.

Note that fossil fuels consist of mixtures of different compounds, all of which contain carbon bonded to other types of atom (often hydrogen as Table 1 shows). Here, for simplicity, we treat them as if they consisted of these atoms in the elemental form.

☐ Can you write out the balanced chemical equation for the burning of carbon?

■ The burning of carbon, as a balanced chemical equation, is as follows:

$$C + O_2 = CO_2 + heat \qquad (1)$$
carbon + oxygen   carbon dioxide
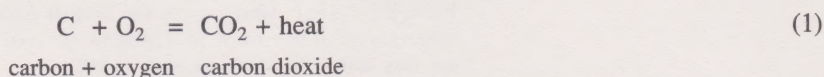
In the case of carbon the chemical equation is easy to balance because one atom of carbon reacts with one molecule of oxygen, which contains two atoms of oxygen. You may recall that this is the state in which oxygen naturally occurs in the atmosphere.

Especially in the case of gas and oil, some of the heat comes from the combustion of the hydrogen in the fuel according to the following equation:

$$H_2 + O_2 = H_2O + heat$$
hydrogen + oxygen   water
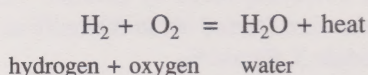
☐ This equation is not balanced; try to balance it.

■ $2H_2 + O_2 = 2H_2O + heat$ $\qquad (2)$
Two molecules of hydrogen combine with one molecule of oxygen to form two molecules of water and heat.

Let's look at the products of these two reactions in more detail. The products of burning both carbon and hydrogen are gases. You will be aware that all the petrol put into a car ends up as exhaust gases, see Figure 2.
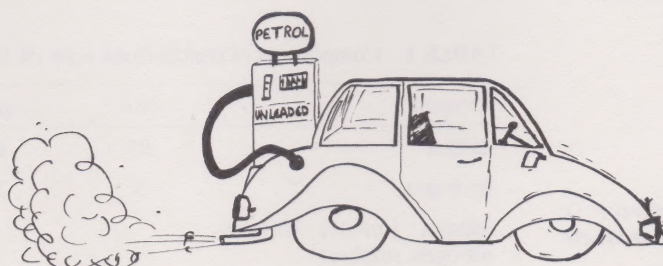

FIGURE 2   Where does all the fuel go?

Carbon dioxide is always produced as a gas. Water is a gas at temperatures above its boiling point (100 °C), which is always achieved when fossil fuels are burned. Both these chemical reactions involve *taking oxygen out* of the atmosphere and both these combustion products, CO_2 and H_2O, are *added to the atmosphere*. We need to know how the addition of these gases will affect the composition of the atmosphere.

Let us consider H_2O first. Modules 5/6 showed that there are already huge amounts of water vapour circulating through the atmosphere, so adding some more makes little difference (although it may increase mists and rain locally).

☐ Can you remember the difference in the behaviour of molecules of liquid water and water vapour (see Modules 5/6, Figure 26).

■ Water vapour molecules have a higher speed of movement, compared to those of liquid water. In Module 8 this was expressed in another way, by saying that water vapour has a *higher kinetic energy* than liquid water.

The situation with CO_2 is very different from that of H_2O because CO_2 is only a very minor natural constituent of the atmosphere, (see Section 4 below), and so addition of large amounts of this gas by combustion is of more concern.

In a similar way that steam from a kettle quickly disperses into a room, the large amounts of carbon dioxide from power stations and cars are mixed with the other gases in the atmosphere and dispersed. The process by which this is brought about is called **diffusion**, as explained in the Box.

DIFFUSION

Carbon dioxide is a very dense gas, much denser than air. Thus it can be expected to be useful when used in fire extinguishers as the dense gas is effective at 'blanketing out' a fire. So, why don't we all suffocate in the huge amounts of carbon dioxide produced by burning of fossil fuels? The reason is that all gases mix together very rapidly, that is they diffuse into each other. Very small amounts of a strong-smelling gas (for example, fumes from a pan of warming vinegar, or cooking bacon) can be picked up across a large room in a few seconds. This observation gives an indication of the speed at which gases in the atmosphere mix with each other. This mixing of gases can be explained by the high speeds at which the molecules are moving in all gases. Similarly, however carefully you pour milk into a cup of tea, the two liquids soon become completely mixed together by diffusion.

So how does the amount of CO_2 from fossil fuel burning affect the CO_2 content of the atmosphere? Before trying to answer this, we need to look at the relative amounts of CO_2 produced by each of the three fuels. This is the topic of the next Section.

3 AMOUNTS OF CARBON DIOXIDE PRODUCED BY FOSSIL FUEL BURNING

By 'amount' of carbon dioxide we mean 'mass'. Thus the question is: what mass of CO_2 is produced when a certain mass of fuel of a particular type is burned? To work this out we need to know the chemical composition of the fuel (from Table 1), and the relative masses of each of the atoms in the fuel. In Modules 5/6

you met the concept of the relative atomic masses of atoms, that is the mass of each atom relative to the lightest atom, hydrogen, which is given the mass of 1. You also learned that there are huge numbers of atoms in a few grams of carbon (for example, 12 grams of carbon contain 6×10^{23} atoms). This means that in chemical calculations it is not convenient to work in numbers of atoms, so we work in relative atomic masses instead. The relative atomic masses of the atoms in Table 1 are:

hydrogen (H) = 1

carbon (C) = 12

oxygen (O) = 16

You know that when one atom of carbon is burnt it combines with two atoms of oxygen according to the balanced Equation 1 above.

☐ Can you work out how many grams of carbon dioxide are produced by burning one gram of carbon?

■ From Equation 1 we know that one atom of carbon combines with two atoms of oxygen to form one molecule of carbon dioxide. So, putting the relative atomic masses into Equation 1 shows that 12 grams of carbon combine with 32 grams of oxygen to produce 44 grams of CO_2. Therefore 1 gram of carbon burns to give: $(44/12)\,g = 3.67$ grams of CO_2.

Now try the following SAQs to work out for yourself how much CO_2 will be produced from burning coal. (A tonne is not an SI unit, but is the normal unit used to measure the mass of coal: 1 tonne = 1000 kilograms.)

SAQ 1   How many tonnes of carbon dioxide are produced by burning a tonne of coal whose chemical composition is as shown in Table 1? Give your answer to two decimal places.

SAQ 2   Calculate the amount of CO_2 produced each year by a group of British power stations, assuming that they consume, in total, about 60 million tonnes of coal. This time assume that the coal contains on average 75% carbon. Give your answer in millions of tonnes of CO_2.

In the above SAQ you calculated the amount of CO_2 produced when a given amount of a fossil fuel is burned. The same methods can be used to calculate CO_2 production today in a town or even a whole country, from the total amounts of various fossil fuels consumed. This leads us to the third of our initial questions: how has the CO_2 content of the atmosphere changed with time? This is the subject of the next Section.

4 FOSSIL FUELS, CO₂ AND THE CARBON CYCLE

Our starting point for exploring the tricky question of estimating how the amount of CO_2 in the atmosphere has changed with time, is to construct a simple model of the behaviour of carbon in the natural world. This is called the **carbon cycle** and it is illustrated in Figure 3. The carbon cycle is a way of summarizing the behaviour of carbon in the environment. It has many similarities to the nitrogen cycle described in Modules 5/6 (Figure 21).
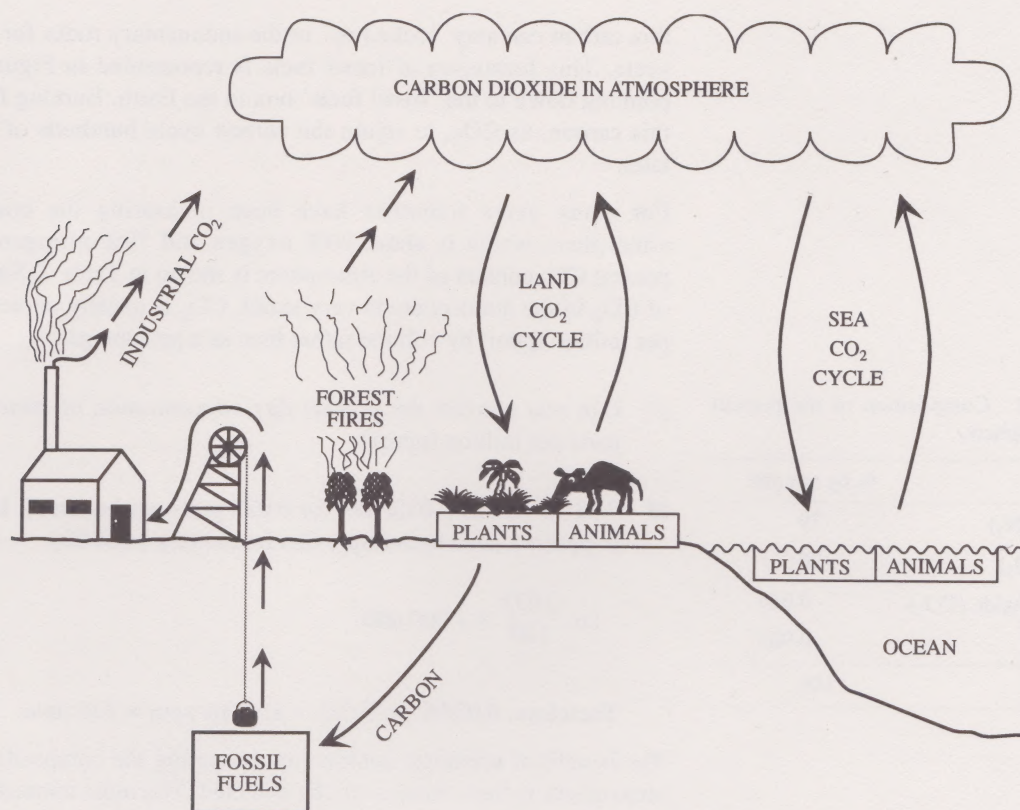
FIGURE 3 Simplified carbon cycle to show the main flows of carbon over land and sea. In the atmosphere carbon is present as CO_2, on land largely as carbon-containing substances in plants and animals, and in the sea mainly as dissolved carbonates, such as calcium carbonate.

Look at the arrows along the left hand side of Figure 3 going up from a box below the Earth's surface, called 'fossil fuels', to the clouds in the sky called 'carbon dioxide in atmosphere'. This set of arrows represents the part of the carbon cycle that was discussed in the previous Sections—the mining and burning of fossil fuels. It represents mining more or less pure carbon from the Earth (e.g. as coal) and burning it to release the carbon into the atmosphere as CO_2 gas. The burning of forests is also shown in this part of the cycle. These two activities represent the human input to the carbon cycle.

The rest of the carbon cycle is governed by natural biological processes and can be considered in two separate parts, one operating on land and the other over the sea. The central part of Figure 3 (land CO_2 cycle) shows that plants use CO_2 from the atmosphere during photosynthesis, and that animals and plants release CO_2 back to the atmosphere during respiration (see Module 7). A similar circulation of CO_2 occurs over the sea as shown by the right hand part of Figure 3. Thus, by representing the routes by which carbon flows through the environment, we have built a simple model of the carbon cycle.

The main human contribution to the carbon cycle is to *add* CO_2 to the atmosphere by mining and burning fossil fuels and forests—in effect *taking* carbon *from* the ground, whereas the main human contribution to the nitrogen cycle (Modules 5/6) is the reverse, nitrogen is removed from the atmosphere and *added* to the ground as solid nitrates.

Figure 3 is a very simplified representation of the flow of carbon through the environment and we could create a more complete model by adding in other flows of carbon. For example, the bodies of both plants and animals decay after death, and as they are decomposed by bacteria most of their carbon is released as CO_2 to the atmosphere.

Since bacteria breakdown and release carbon from dead and decaying material, how was it possible for fossil fuels to form? They formed over millions of years from those parts of plants and animals which *escaped* decay after death by being trapped in sediments *before* the carbon was converted into CO_2. Once buried,

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this carbon can stay 'locked up' in the sedimentary rocks for many millions of years. This formation of fossil fuels is represented in Figure 3 by the arrow pointing down to the 'fossil fuels' box in the Earth. Burning fossil fuels returns this carbon, as CO_2, to rejoin the carbon cycle hundreds of millions of years later.

For many years scientists have been measuring the composition of the atmosphere which is about 20% oxygen and 79% nitrogen by volume. The present CO_2 content of the atmosphere is shown in Table 2. Since the percentage of CO_2 in the atmosphere is very small, CO_2 is usually quoted in units of parts per million (ppm) by volume rather than as a percentage.

TABLE 2 Composition of the present-day atmosphere.

Gas	% by volume
nitrogen (N_2)	79
oxygen (O_2)	20
carbon dioxide (CO_2)	0.035
others	0.965
totals	100

☐ Can you convert the present day concentration of atmospheric CO_2 into parts per million (ppm)?

■ 0.035% means 0.035/100, (or 0.035 parts per hundred). In order to convert to ppm we need to multiply this fraction by 1 000 000

i.e. $\frac{0.035}{100} \times 1\,000\,000$

Therefore: $0.035\% = (0.035 \times 10\,000)$ ppm = 350 ppm.

The benefit of scientists continually measuring the composition of gases in the atmosphere is that changes can be detected. The most interesting results for our discussion are the increases in atmospheric CO_2 which have occurred over recent years, as shown in Table 3.

In order to see more clearly what has been happening to CO_2 levels we suggest that you plot this data as a graph. This graph will show at a glance how CO_2 has been increasing in recent years. Before plotting the graph let us consider one or two features of the data to be plotted.

You have plotted graphs like this before, in Module 7 (yeast growth), and in Module 8 (cooling curve). Remember that the horizontal axis is usually chosen for the independent variable, and the vertical axis for the dependent variable.

TABLE 3 Recent measurements of atmospheric CO_2 concentrations (ppm).

Date	CO_2 concentration
1950	310
1955	312
1960	314
1965	317
1970	322
1975	328
1980	335
1985	343
1990	352
1995	
2000	

☐ What is the independent variable here?

■ Time.

The origin of the graph need not necessarily be zero, as you discovered with the cooling experiment in Module 8. It needs to be chosen to make a sensible starting point for each axis, without wasting a lot of space on the graph.

☐ What would you chose as the origin for each axis?

■ 1950 for the x axis because no data are given before 1950. For the y axis we chose 300 ppm (as it is a round number) but we could have chosen 310 ppm, the smallest value measured for CO_2.

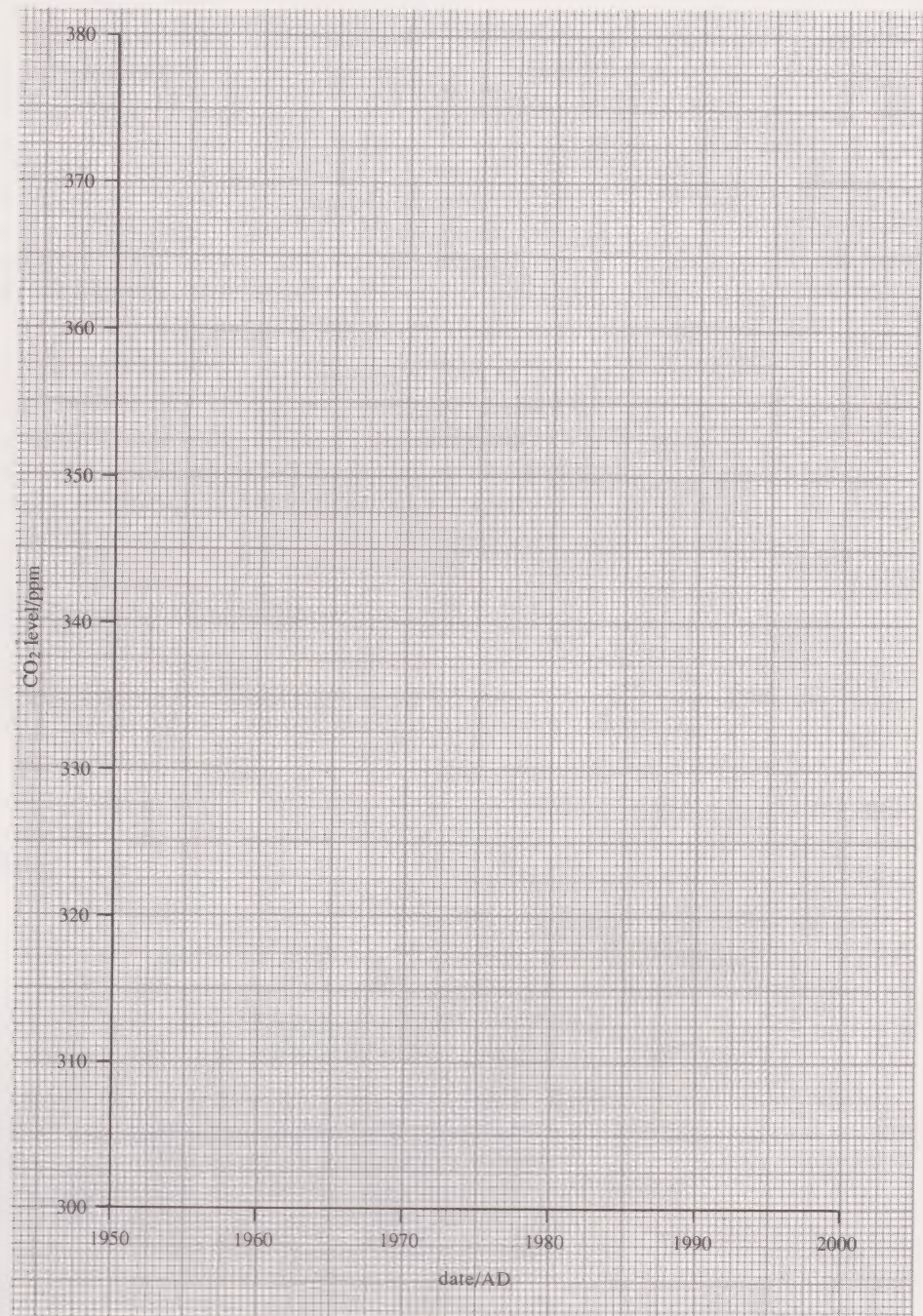The axes have been drawn for you on Figure 4.

FIGURE 4   Graph to show increase of CO_2 from 1950–1990 AD using data from Table 3.

Using the CO_2 data in Table 3, plot a graph on Figure 4 to show the increase in the concentration of atmospheric CO_2 from 1950–1990 AD. When you have done this, compare your answer with ours which is given in Appendix 2, Figure 11.

The data in Table 3 and your graph show the rise in CO_2 concentration between 1950 and 1990. But we are interested in how CO_2 is likely to increase in the future, and estimating this is a little more difficult because the data stops at 1990. To make an estimate for the year 2000 AD you will have to predict the information into the future, a process known as **extrapolation**. There are two ways of doing this.

(i)   The first way is by completing Table 3.

☐   Can you fill in the missing figures in Table 3 for the CO_2 values up to the end of the century, that is, can you *predict* the CO_2 levels into the future?

■   The easiest way to approach this task is to first work out the *average* rate of increase for the period. The difference between the CO_2 levels in the 40 years 1950–1990 is 42 ppm. That is an average yearly rise of: 42/40 = 1.05 ppm per year. So, if this average rate was maintained for the next ten years, the figures would be: for 1995, 357.25 ppm (5.25 + 352) and for 2000, 362.5 ppm (10.5 + 352).

But these values will be too low because the *rate* at which the gas is building up in the atmosphere is *increasing* with time. This is shown by the data in Table 3. If you look at the rate of CO_2 increase for each five-year period starting with 1950–55, the figures are: 2, 2, 3, 5, 6, 7, 8, 9. If this rate of increase is maintained, CO_2 may rise by firstly 10 ppm and then 11 ppm for the next two five-year periods. Thus the two numbers to complete Table 3 would be 362 ppm for 1995 and 373 ppm for 2000 AD.

(ii)   The other way of estimating the CO_2 increase is by using the graph you have drawn.

☐   Can you estimate the likely amount of CO_2 in the atmosphere for the year 2000 AD from your graph?

■   Our answer, which we produced in two ways, is given in Figure 11 (Appendix 2). The broken line was obtained by extending or extrapolating the last two results, for 1985 and 1990, in a straight line. If this continued to 2000 AD it would give a figure of about 370 ppm. However, this is a conservative estimate because we know that CO_2 is building up at an increasing rate. The more likely result is shown by the solid line in Figure 11, which has been drawn by connecting the data points from 1950 to 1990 by a smooth curve and extrapolating this curve into the future. If this continued to 2000 AD it would give a figure above 375 ppm.

If the processes which have been responsible for the increase of CO_2 over these 40 years are going to operate in the same way for the following 10 years, then continuing this smooth curve is a fair way to proceed. But if there is a sudden change then your extrapolation will be unreliable. Political pollsters and economic forecasters have exactly the same problems with extrapolation, because human behaviour is *very* difficult to predict.

Since we do not yet know for certain what is causing the increase in CO_2, extrapolation is unreliable. We are projecting forward 10 years on the basis of only having data for 40 years. Furthermore, we know that CO_2 is not increasing uniformly. If the data points on your graph formed a straight line then extrapolation would be more certain.

To be more confident about making any prediction for the future it is sensible to look for further relevant information. Part of our dilemma here is that although the data in Table 3 show a real increase of CO_2, we have not yet *proved* that this increase is due to burning fossil fuels. We look at further supporting evidence in Section 6.

However, as this 'forecasting' is so important to understanding the CO_2 changes, it is useful to look at another powerful illustration of just how difficult it is to predict the future where the data lie on a steeply curving graph. A more familiar problem is that of the world's increasing population. Again we have reliable information about the past, and can see that the rate of population growth has been increasing. But the crucial question is how will the population grow in the future?

5 INCREASE IN WORLD POPULATION

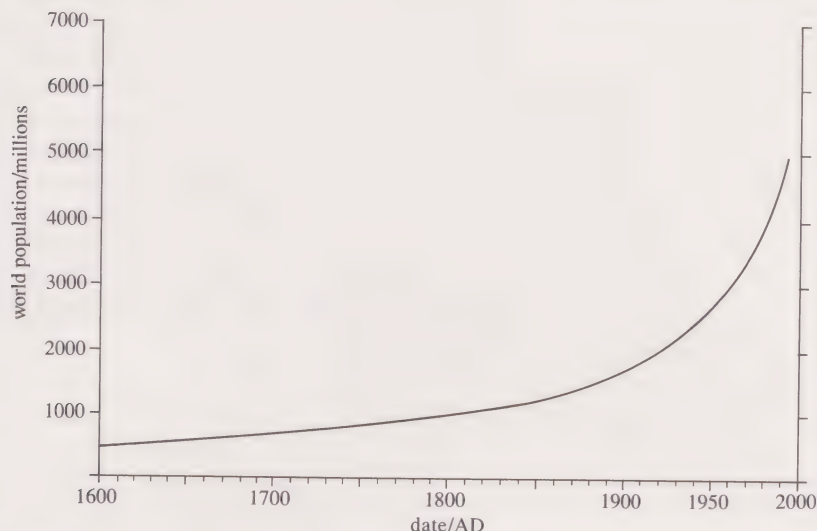The increase in the world's population between 1600 AD and the present is shown in Figure 5.

FIGURE 5   The increase in world population from 1600 AD to the present.

Look at this graph, and try to answer the following questions:

☐   Can you draw any conclusions about the rate of increase in the world's population before 1600?

■   It is tempting to say that there was a steady but small growth. However, since there is no data given, this conclusion rests solely on the extrapolation back in time of the straight line at the left hand end of the graph.

☐   Was the population rising faster between 1900 and 1990, or between 1600 and 1800?

■   It was rising much faster between 1900–1990, because the gradient of the graph is much steeper than between 1600–1800.

☐   From the data shown on the graph, can you tell the main reason for the greater increase in the world population at the present time as compared to a century ago?

■   No, the data in the graph tell us *nothing* about the reasons for the change. For that we need to collect information about the many factors which affect population growth, such as the causes of death and birth rates in various countries and at various times.

When we are dealing with a complex situation such as the increase in world population, it is often necessary to erect and test a model and then try to work out how the different parts of the model interact with each other to bring about the final numerical result. It is clear that many factors alter the birth and death rates, from very rapid events such as natural disasters, to much longer term factors such as improvements to agriculture. A model which tried to allow for all the factors which have had an influence on world population growth for the last 400 years would be very complicated indeed!

Similarly, although it is clear that CO_2 has increased rapidly over the last 40 years (Figure 4), more information is needed before we can speculate as to the exact cause of this increase. In the next Section we look at changes in CO_2 in the atmosphere over a much longer timescale.

6 INCREASE OF CO$_2$ IN THE ATMOSPHERE: EVIDENCE FROM ICE CORES

When snow falls in areas of the world which are at freezing temperatures for most of the year, it tends to accumulate to form thick layers of ice. These eventually form massive **glaciers** or sheets of ice. In places where thick ice masses have formed, the ice at the bottom can be many thousands of years old. Minute bubbles of air become trapped as the snow falls, so that samples of the atmosphere become trapped in the ice. Scientists have drilled through the ice sheets in places like Greenland, to recover ice cores which provide samples of ancient ice. After melting the ice, the trapped air has been collected. Thus it is possible to measure the amounts of CO$_2$ in individual layers of ice and compare them with the present value of CO$_2$ in the atmosphere. Figure 6 shows the results from some of these air samples, obtained from ice cores, going back several hundred years.
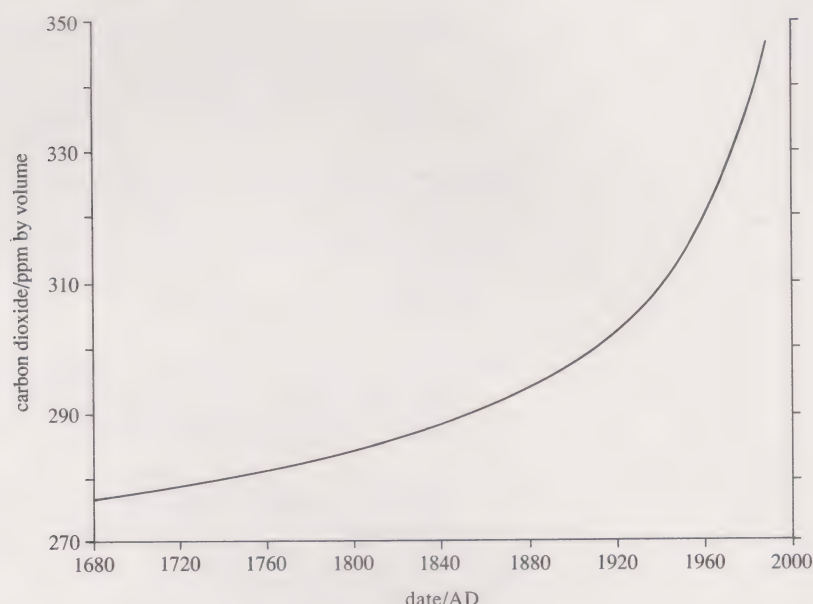

FIGURE 6   Increase in atmospheric CO$_2$ from 1680–1990 AD as measured from ice cores.

Figure 6 is similar to your Figure 4, but the graph here has information for a much longer period of time, starting well before the beginning of the Industrial Revolution (at the end of the 18th century). We know that the onset of industrialization in Europe was marked by a very rapid increase in the consumption of fossil fuels, particularly the burning of coal for heating and powering steam-driven machinery.

☐   By about how much has CO$_2$ increased in the atmosphere between 1800 and 1900?

■   About 13 ppm, from about 285 ppm to about 298 ppm.

☐   Does the information in Figure 6 *prove* that the increase of atmospheric CO$_2$ in the last two hundred years is due to fossil fuel consumption?

■   No, just as the data in Figure 5 told us nothing about the *causes* of world population increase, this graph cannot prove any statement about the causes of increasing CO$_2$. However, it certainly does provide *support* to the idea that at least some of the increase in CO$_2$ is *likely* to be due to fossil fuel burning. This is because there seems to be a steady and accelerating

increase in CO_2, over the period during which industrialization was accompanied by increased fossil fuel consumption.

So the data in Figure 6 provide good supporting evidence that much of the increase of atmospheric CO_2 could be due to burning fossil fuel, and is *consistent* with our model (Figure 3). But we are not yet able to *prove* in any scientific way that CO_2 is increasing solely because of fossil fuel burning.

The next step is to test the model by trying to put quantities into the carbon cycle, shown in Figure 3. We need to see if the amounts of CO_2 released by fossil fuel burning are consistent with the increase of CO_2 seen in the atmosphere. This is the subject of the next Section.

7 QUANTIFYING THE CARBON CYCLE

7.1 FLOWS AROUND THE CARBON CYCLE

In this Section we take a closer look at the carbon cycle to see if we can quantify how important CO_2 from burning fossil fuels might be in the overall scheme of things. Look at Figure 7, which is a development of Figure 3, where the amounts of carbon flowing around the parts of the carbon cycle each year are shown.
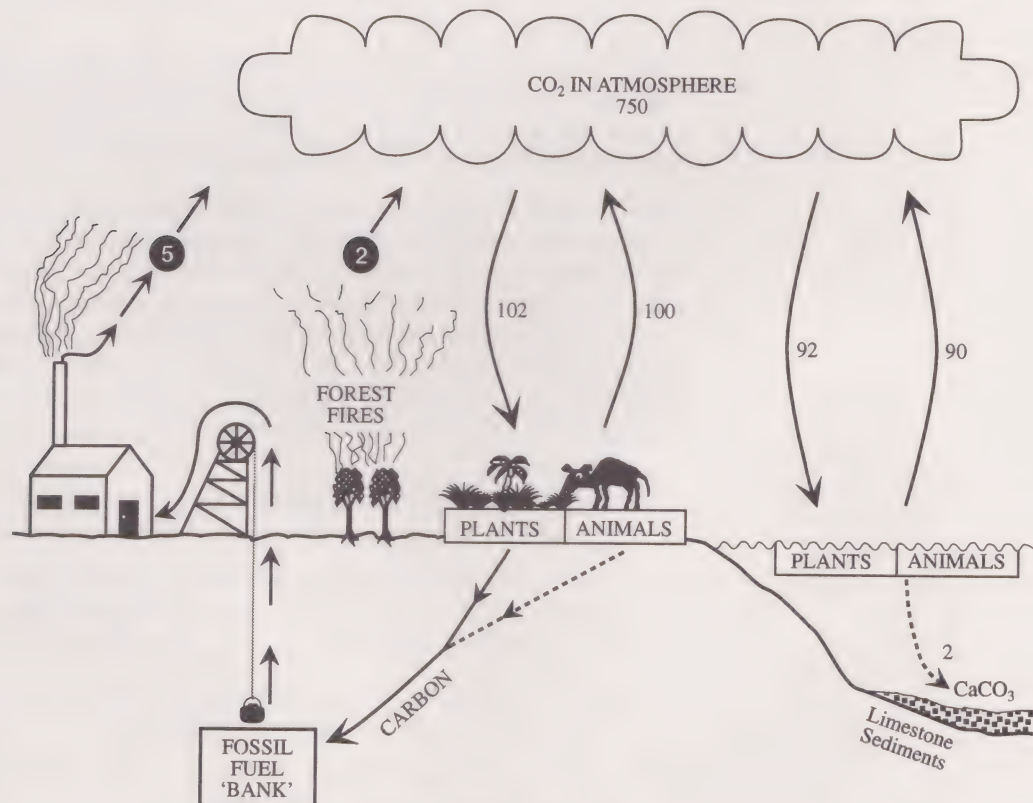

FIGURE 7 Simplified model of the present day global carbon cycle, showing the amounts of carbon involved. The number in the clouds, is the total amount of carbon (in units of 10^9 (billions) of tonnes of carbon as CO_2) present in the atmosphere today. All other numbers refer to annual *flows* of 10^9 tonnes of carbon per year around the parts of the cycle. For simplicity, all the masses refer to pure carbon regardless of the actual chemical compounds involved.

☐ What can you deduce from Figure 7 about the contribution of human activities, fossil fuel and forest burning, to the overall carbon cycle? (Assume all forest fires are of human origin.)

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■ These activities add about 7 billion tonnes of carbon as CO_2 to the atmosphere each year, of which about 5 billion tonnes of carbon are from fossil fuels and about 2 billion tonnes of carbon are from forest fires (white numbers in black discs).

The black numbers in Figure 7 show the amount of carbon moving each year through the two parts of the natural carbon cycle. Firstly, about 100 billion tonnes of carbon circulate over the land (centre of Figure 7), and secondly, about 90 billion tonnes of carbon circulate over the sea (right of Figure 7). These annual flows around the carbon cycle can be compared to the present total amount of carbon (as CO_2) in the atmosphere of about 750×10^9 tonnes.

It is interesting to compare the carbon cycle with other cycles. The nitrogen cycle has an annual flow of less than 300 *million* tonnes per year although nitrogen makes up 80% of the Earth's atmosphere. The flows around the world's carbon cycle are nearly a thousand times as great, at about 200 *billion* tonnes per year of carbon, although carbon dioxide forms only a trace of the atmosphere. The world's water cycle is very much bigger still.

There is a striking difference between the human-driven part of the carbon cycle on the left of Figure 7 (white numbers), which is *adding* CO_2 to the atmosphere at about 7 billion tonnes of carbon per year, and the two natural parts of the cycle in the centre and right of Figure 7, which are *removing* more CO_2 from the atmosphere each year than they are returning to it. The next subsections look at these different parts of the carbon cycle in more detail.

7.2 THE OCEANS, LIMESTONES AND CO_2

The part of the carbon cycle over the oceans, on the right of Figure 7, indicates that about 2 billion tonnes *more* carbon is taken up by the oceans than is released back to the atmosphere. Where does this CO_2 go? It looks as though the world's oceans are acting as a 'sink' for atmospheric CO_2. How does this work?

Most of the CO_2 absorbed by the oceans contributes to the growth of marine life. You may remember from Module 3 that limestones are formed almost entirely of the mineral calcite, in the form of the remains of sea creatures such as shells. These are made of the chemical compound calcium carbonate, $CaCO_3$. Limestones are formed in the following way. CO_2 from the atmosphere dissolves in the ocean. Animals extract the CO_2 and react it with calcium (also found in solution in the ocean) to form their shells. After these creatures die their shells accumulate as a layer on the sea floor to form limestones.

☐ If all of the carbon 'lost' from the cycle over the oceans eventually forms limestone, at what rate are limestones accumulating today?

Clue 1 You will need to use a chemical equation for limestone formation. (Strictly 'CaO' is not a distinct compound found in the ocean, but it will serve here for our purposes.) The equation is: $CaO + CO_2 = CaCO_3$.

Clue 2 You also need to know the relative atomic masses of the elements concerned: calcium, 40; carbon, 12; oxygen, 16.

■ According to Figure 7 there is a loss of 2×10^9 tonnes $(92 - 90)$ of carbon per year from the oceanic part of the carbon cycle. If all this carbon is laid down eventually as limestone sediment on the ocean floor according to the equation:

$$CaO + CO_2 = CaCO_3$$
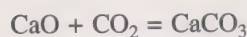
Then the relative masses are:

$$(40 + 16) + (12 + 32) = (40 + 12 + 48)$$

$$56 + 44 = 100$$

Thus, 12 tonnes of carbon will form 100 tonnes of limestone, so 1 tonne of carbon will form $100/12 = 8.33$ tonnes. Therefore, 2×10^9 tonnes of carbon will form $8.33 \times 2 \times 10^9$ tonnes $= 16.7 \times 10^9$ tonnes of limestone per year.

This carbon becomes 'locked up' in limestone rocks. Many limestones are hundreds of millions of years old and some more than a thousand million years old. Thus the carbon removed from the atmosphere by limestone formation can be out of circulation for a very long time!

7.3 LAND PLANTS, CO_2 AND FOSSIL FUELS

The part of the cycle in the middle of Figure 7 represents processes occurring on land. There are many chemical reactions involved here, but the most important one is photosynthesis by plants to fix the carbon from atmospheric CO_2 in plant tissues (the 102 'down' arrow). Respiration by animals and plants uses oxygen from the atmosphere and releases CO_2 back to the atmosphere (the 100 'up' arrow).

As with the carbon cycle over the oceans, there is apparently a 'sink' for carbon on land. Where does it go? Much of it accumulates in vegetation in peat bogs, swamps, wood in trees and on the ground as humus (decaying plant material such as leaves). Natural forest fires return some of this carbon to the atmosphere, but many forest fires today result from human activities. The important point for our purposes is that only a minute amount of the carbon, less than 1% of dead plant material, ever gets preserved in rocks and only a small part of this becomes concentrated enough to form part of the fossil fuel 'bank' (represented by the arrow 'carbon' below the ground).

7.4 BURNING FOSSIL FUELS AND FORESTS

The left hand side of the figure shows that burning fossil fuels world-wide probably contributes about 5 billion tonnes of carbon as CO_2 to the atmosphere each year, to add to the 2 billion tonnes from forest fires. These two figures are based on the known tonnages for world fuel consumption and an estimate of the wood destroyed each year by burning forests.

7.5 VOLCANIC PRODUCTION OF CO_2

Sometimes changes in CO_2 concentrations can be related to natural events. For example, volcanic explosions can release huge quantities of CO_2 into the atmosphere. In 1991 Mount Etna in Sicily erupted, and lava-flows (which were shown on the TV news) ran down the mountain to threaten villages. At the same time this hot lava released about 13 million tonnes of CO_2 as it came to the surface and cooled. However this volcanic CO_2 is small compared to the amounts in Figure 7.

Now we have an idea of the amount and rate of flow of carbon around the natural carbon cycle, and how much human activity is adding to the cycle. We have already measured how fast atmospheric CO_2 is increasing (Figures 4 and 6), so we are now in a position to answer the next question. How does the rate of increase of CO_2 in the atmosphere compare with the amounts of carbon added each year by human activities? This is the subject of the next Section.

8 FOSSIL FUEL CONSUMPTION AND INCREASING ATMOSPHERIC CO_2 LEVELS

In this Section we compare the actual increase in atmospheric CO_2 measured at the present time (Figure 4), with the increase we would expect from the annual amounts of carbon added by burning fossil fuels and forest fires (Figure 7).

GUIDED EXERCISE 1

How fast would CO_2 be increasing in the atmosphere today, if all the CO_2 from forest fires and fossil fuel burning was accumulating in the atmosphere? (Give your answer as a % increase of the present day amount of atmospheric CO_2.)

The simplest way to approach this question is to compare the carbon added to the atmosphere from burning of forest fires and fossil fuels each year, with the total amount of CO_2 already in the atmosphere.

Figure 7 shows that carbon added to the atmosphere as CO_2 by these human activities each year is $(5 + 2) \times 10^9 = 7 \times 10^9$ tonnes (assuming most forest fires are of human origin). This also shows the amount of carbon as CO_2 already present in the atmosphere today $= 750 \times 10^9$ tonnes.

Therefore, as a percentage, the annual addition of carbon as CO_2 is:

$$\frac{7}{750} \times 100\% = 0.93\% \text{ per year}$$

This suggests an increase in CO_2 of about 1% a year.

GUIDED EXERCISE 2

How does this increase of about 1% a year of CO_2 compare with the average rate of increase of CO_2 actually observed (Table 3) for the period 1980–90? Give your answer in % per year.

From 1980–90, CO_2 increased from 335 to 352 ppm, an increase of 17 ppm in 10 years.

That is:

$$\frac{17}{10} \text{ ppm per year} = 1.7 \text{ ppm per year.}$$

The present concentration of CO_2 in the atmosphere is 352 ppm.

Therefore as a percentage of the total amount in the atmosphere, the observed rate of CO_2 increase between 1980–1990 was:

$$\frac{1.7}{352} \times 100 = 0.48\% \text{ per year.}$$

So the observed rate of increase of CO_2 is about 0.5% per year, or about half of that calculated in Guided Exercise 1.

These two exercises show that carbon is being produced by human activities at the rate of 7 billion tonnes per year—enough to cause an increase of atmospheric CO_2 of about 1% per year. However, it is actually building up in the atmosphere at only half that rate, equivalent to 3.5 billion tonnes per year of carbon, causing an increase of only 0.5% of CO_2 in the atmosphere. Therefore, it looks as though about one half of the CO_2 from fossil fuels and forest fires is being removed from the atmosphere by natural processes. So, where is the remaining CO_2 going?

There are two possibilities as we saw in Section 7. Some is used up in making calcium carbonate in the oceans (bottom right of Figure 7), and probably this is where most of it ends up ready to form the limestones of the future. Some may end up 'trickling' into the fossil fuel bank (bottom left of Figure 7), but probably in only very small amounts. We have now discussed all the figures in the carbon cycle in Figure 7.

By constructing a simple model of the natural carbon cycle, as shown in Figure 7, and calculating the additions to this cycle from fuel and forest burning, we have shown that the observed increase in atmospheric CO_2 is about half of the CO_2 estimated to be produced by human activities. We still have not actually *proved* that increasing CO_2 levels are entirely due to these human activities, but the amounts of CO_2 involved are entirely *consistent* with our simple model of the carbon cycle. Models like this are very useful ways of formalizing our thinking and testing ideas.

Consider the opposite scenario for a moment. If the actual rate of atmospheric CO_2 increase had been many times *greater* than the CO_2 output from human activities, then our model of CO_2 build-up in the atmosphere being due to fossil fuel burning would *not* be consistent with the measured data. In science, showing that one of two alternative ideas is wrong (or one is less likely than the other) can be an important step forward. Having shown that CO_2 in the atmosphere is increasing, the next Section looks briefly at the possible climatic changes that might be brought about by this rise in atmospheric CO_2.

9 ATMOSPHERIC CO_2 AND CLIMATE CHANGES

You have probably heard of the so called 'greenhouse effect'. There is a constant stream of articles in the press warning of the threat of imminent 'climate change' or 'global warming' and consequent coastal flooding due to a rise in sea level.

CO_2 is believed to be responsible for about half of the so called 'greenhouse effect' of the Earth's atmosphere, the rest comes from other gases generated by human activities. How does an increase in these gases lead to the greenhouse effect? To answer this let's look at how a greenhouse works.

Greenhouses provide warmer places than the garden for plant growth because glass is transparent to incoming sunlight (rich in light of relatively short wavelengths) and is much less transparent to the radiant heat radiating back from the soil (of longer wavelength, see Module 4 and Module 8). The result of these properties of glass is that some of the heat energy is trapped inside the greenhouse so it heats up. Scientists believe that several of the gases present in the Earth's atmosphere act to trap heat at the surface in exactly the same way as glass in a greenhouse (see Figure 8 overleaf).
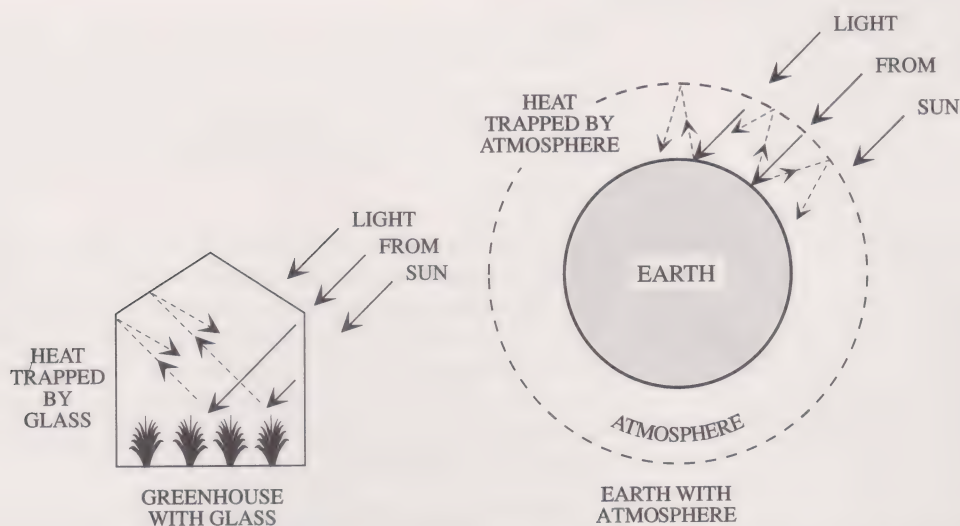
LIGHT
FROM
SUN

HEAT
TRAPPED BY
ATMOSPHERE

EARTH

ATMOSPHERE

LIGHT
FROM
SUN

HEAT
TRAPPED
BY
GLASS

GREENHOUSE
WITH GLASS

EARTH WITH
ATMOSPHERE

FIGURE 8   (a) Heating up of a greenhouse and (b) heating up of the Earth by the Sun the so-called 'greenhouse effect'.

10 IS CO$_2$ FROM FOSSIL FUELS CAUSING CLIMATE CHANGE?

Just as we are able to work out the past CO$_2$ content of the atmosphere by analysing samples of 'fossil' air trapped in the Greenland ice sheet (Section 6), it is also possible to collect information from historical records about past climates. There are a number of ways this can be done. Documentary records of 'bad' winters can be consulted. Also the sizes of tree rings can be measured since their width indicates the amount of growth that year. From these sources we know that there have been considerable changes in average temperatures in the recent past. Some of this information is plotted in Figure 9 which shows how the temperature has varied in Great Britain over the last thousand years or so. Also shown are recent estimates of the temperature changes to be expected for the next 100 years.

Present
day

WARMER

temperature change from today's average/ °C

+4

+3

+2

+1

Today's
Average
Temperature

0

COOLER

−1

−2

Vikings in
Greenland

Medieval Warm
Period

R. Thames
frozen regularly

'Little Ice Age'

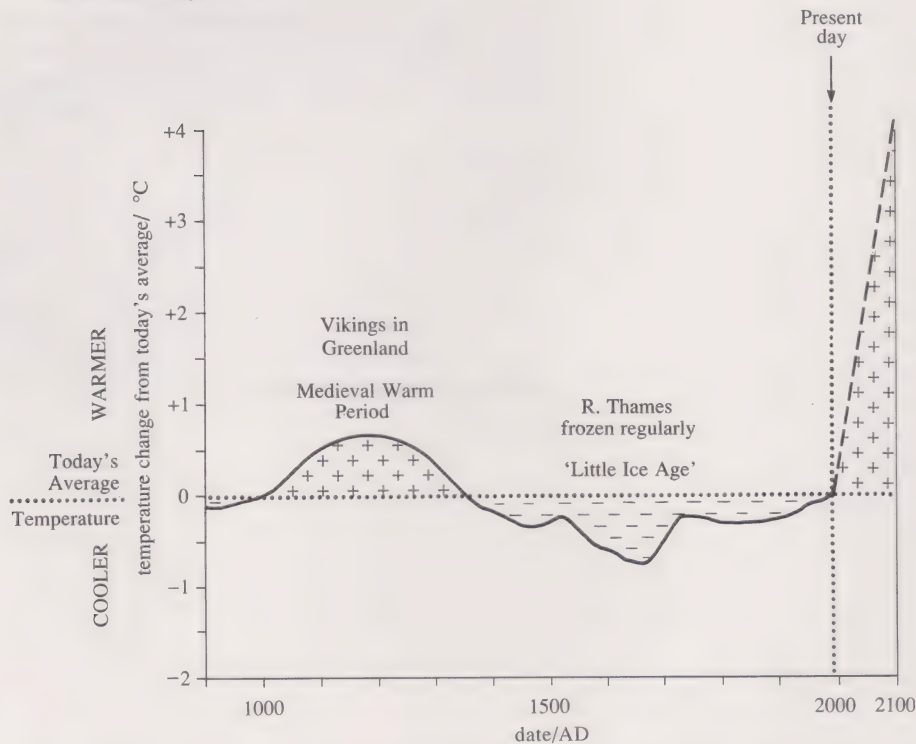1000   1500   2000   2100

date/AD

FIGURE 9   Average temperatures in Great Britain between 900 AD and the present from historical records, and predicted temperatures to 2100 AD.

In Figure 9 the horizontal axis shows time from 900–2100 AD. The vertical axis of the graph may appear a little tricky to interpret at first sight. It shows the temperature, in degrees Celsius, as a *difference* from today's average temperature. What does this mean? The average temperature today is about 15 °C, and this is represented on the graph by the dotted horizontal '0' line. All periods which lie below this horizontal '0' line were *colder* than today and those above the line were *hotter* than today. The origin of the vertical temperature scale at −2 °C represents 2 °C cooler than today. The temperature scale runs up to +4 °C, that is 4 °C hotter than today.

Now look at the shape of the graph itself. It has been drawn as a smooth line through the points of best estimates of temperatures from a wide variety of historical sources. It clearly shows a period in medieval times warmer than the present, from about 1000–1300 AD, and a period colder than the present, from about 1400–1900 AD.

This graph is the best record we have of past UK average temperatures. So, we can use it to interpret the past climate, and to compare the past rates of natural climate change with those predicted for the future. Some experts predict the temperature might reach +4 °C by the year 2100 AD, and this is shown by the broken line running to the year 2100 AD.

☐ What was the average rate of temperature change per year between 1000 and 1100 AD?

◼ From Figure 9, in 1000 AD the temperature was just about on the horizontal line labelled '0'. In 1100 AD it was about +0.5 °C. Therefore rate of temperature increase:

= +0.5 °C in 100 years = +0.5 °C /100 = 0.005 °C increase per year.

SAQ 3 If the experts are correct in their predictions, how much faster than 0.005 °C per year is the temperature likely to rise between the present day (assume this to be 1990) and 2100 AD? Check your answer before going on.

The answer to SAQ 3 indicates that warming could be much faster in the next century than at the start of the period of medieval warming.

Is it likely that such a large increase in temperature will *actually* occur in the future, and if so, will it be caused by the greenhouse effect of CO_2? The calculations and the model upon which such predictions rest are very complex, and many assumptions have to be made about the future use of fuels, the climate changes due to gases from human activities (there are many others besides CO_2), and changing weather patterns. So it is not possible to answer this question definitely. Figure 9 represents the best estimates of the world's average temperature increase towards the year 2100 AD made by the climate experts.

In the calculations used to extrapolate data in Figure 9 into the next century it is assumed that CO_2 produced by human activities will be responsible for about half of the temperature rise shown. From records of the more distant past, can we find any evidence of rapid temperature changes like the one predicted for the next century? For this we need to consider results over a much longer timescale, such as those shown in Figure 10, overleaf.
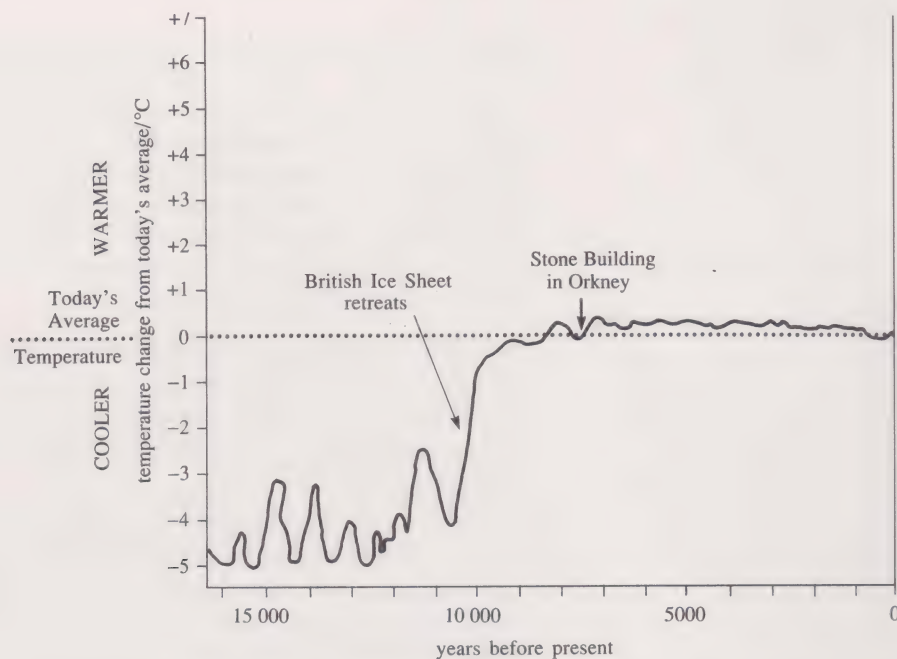
FIGURE 10   Temperature fluctuations from the present day back to beyond 15 000 years before the present.

The vertical axis on Figure 10 is similar to that for Figure 9. The horizontal axis here is different. It shows 'time before the present', and goes 'backwards' in time, starting from an origin at the present day (0) on the *right* with numbers of years *increasing* to the left.

Figure 10 goes back well into the last **Ice Age** which ended about 8000 BC (10 000 years ago). During this ice age average world temperatures were about 5 °C lower than at present.

With this information it is possible to see the rate of warming at the end of the last Ice Age, and to compare this rate with the estimate of the likely rate of temperature rise by the year 2100, as shown in Figure 9.

☐   About how fast did temperature rise per year at the end of the last Ice Age between 10 500 and 10 000 years before the present?

■   Temperature rose from about −4 °C 10 500 years ago to about −1 °C 10 000 years ago. This gives a rate of increase of about 3 °C in 500 years, i.e. 0.006 °C per year.

☐   Now compare this with the the rate of temperature rise which was calculated for the next century in SAQ 3.

■   For the answer to SAQ 3 we got an increase of about 0.036 °C per year. This is six times faster than the 0.006°C per year that the temperature rose at the end of the last Ice Age.

It is unlikely that the temperature rise at the end of the Ice Age was due to fossil fuel burning, as large scale coal mining did not start until thousands of years later! We suspect that there are many factors which may cause the Earth to heat up and cool down from time to time. Some of these may be related to small changes in the orbit of the Earth around the Sun, and the slight 'wobble' of the Earth on its axis of spin.

The temperature rise at the end of the Ice Age is the fastest one known, but it is still a much less rapid rise than that calculated to be likely in the immediate future. There is no other increase in temperature known from the past which is as fast as that predicted for 1990–2100 AD.

A further prediction is that an average 4 °C warming world-wide could cause sea levels to rise by as much as a metre, but that is another story and one that will only become clearer as further work is done.

You are now in a position to reconsider the original questions posed at the beginning of the Module. This Module has examined the increase in CO_2 due to human activity and considered the effect of this increase on global warming. We have not *proved* that climate change will occur in the future due to fossil fuel burning, but all the information so far is *consistent* with this idea.

SAQ 4 How many tonnes of CO_2 is being added to the Earth's atmosphere today by the burning of carbon in fossil fuels and forests (Figure 7)? Give your answer to two decimal places.

SAQ 5 From the result of Guided Exercise 2, explain in your own words, whether the amount of CO_2 from fossil fuel burning alone is enough to explain the increasing amount of CO_2 found in the atmosphere today?

SAQ 6 Explain in your own words, how the effects of CO_2 production from human activities are likely to cause global warming?

Finally, some exercises for car drivers, just in case you feel that fossil fuel burning is someone else's problem.

SAQ 7 If a small car is driven for about 25 000 km each year, and the car does about 10 km for each litre of petrol,

a) how many tonnes of fuel are consumed each year?

b) how many tonnes of CO_2 are produced each year using this car? Give your answer to two decimal places.

(Assume that a litre of petrol has a mass of 0.8 kilogram, and contains 80% by mass of carbon; remember 1 tonne = 1000 kg.)

If you find it difficult to visualise what a tonne of petrol and a tonne of CO_2 look like, try converting the answers to SAQ 7 into volumes by attempting SAQs 8 and 9. (Check your answers to SAQ 7 first.)

SAQ 8 To answer this SAQ you need the volume of petrol used by the small car (see SAQ 7). Assume that you are going to be running your car from a remote base, and so have to have fuel for the year delivered in old-fashioned 44 gallon fuel drums, (each drum holds about the same as 22 household buckets or 22 watering cans). How many drums would you need? (1 gallon is about 4.5 litres.)

SAQ 9 To answer this SAQ you need the answer to SAQ 7b. How many 'house-fulls' of CO_2 would you produce in the exhaust fumes of your car, assuming you lived in the house in Figure 20, Module 3, with internal wall dimensions 9.60 m × 5.80 m × 5.00 m high, and with an internal height of the roofspace of 2.00 m? (The density of CO_2 is about 2 kg m^{-3}.)

11 OVERVIEW

SUMMARY

These are the concepts that you have met in this Module:

- Carbon dioxide is the main gas produced by burning fossil fuels, such as coal, natural gas and oil.

- The carbon cycle is a useful way of describing the behaviour of carbon compounds and their relationship to each other in the natural environment.

- By analysing the quantities of carbon in a model of the natural carbon cycle and the amount of CO_2 produced by human activities, we have seen why CO_2 is presently increasing in the atmosphere.

- About half of the carbon dioxide from burning fossil fuels is accumulating in the atmosphere today, while the other half is being incorporated into the carbon cycle and probably ends up as calcium carbonate in the sea.

- By comparing past records with present-day data it can be shown that the Earth is warming up today at a faster rate than at the end of the last Ice Age. It is predicted that changes in the climate may result from this during the next 100 years.

SKILLS

Now that you have completed this Module, you should be able to:

- work out the amounts of CO_2 that are produced from the combustion of fuels of different chemical compositions

- express complex chemical processes, such as the carbon cycle, in a simple diagrammatic form

- perform calculations to test the validity of models, such as the carbon cycle

- read graphs with negative numbers on their axes and with origins above or below zero

- extrapolate data in tables or on graphs to areas where no information has been collected.

APPENDIX 1: EXPLANATION OF TERMS USED

CARBON CYCLE   A model or diagrammatic way of representing the behaviour of carbon in the environment.

COMBUSTION   The chemical reaction when a fuel is burned in air to produce heat and waste gases such as CO_2.

DIFFUSION   The process of natural mixing of two materials into each other, usually applied to gases and liquids. Two or more gases naturally diffuse or mix into each other very rapidly, due to movement of the atoms or molecules of the gases.

EXTRAPOLATION   The projection of data beyond the limits over which it was collected, for example, by continuing the line of a graph.

FOSSIL FUELS   Fuels, rich in carbon, formed many millions of years ago by the partial decomposition of organisms. The main ones are coal, oil and natural gas.

GLACIERS   Masses of ice which accumulate on high mountains and then flow slowly down valleys.

GLOBAL WARMING   A change of climate where the average temperature of the Earth's surface increases.

GREENHOUSE EFFECT   An increase in the Earth's temperature caused by heat from the sun being trapped in the Earth's atmosphere by gases such as carbon dioxide.

ICE AGE   A period of geological time when the climate was much colder than at present and large sheets of ice covered much of northern Europe. The last ice age finished about 10 000 years ago.

MODEL   A simplified way of showing how components of a complex system are related to each other, for example the carbon cycle.
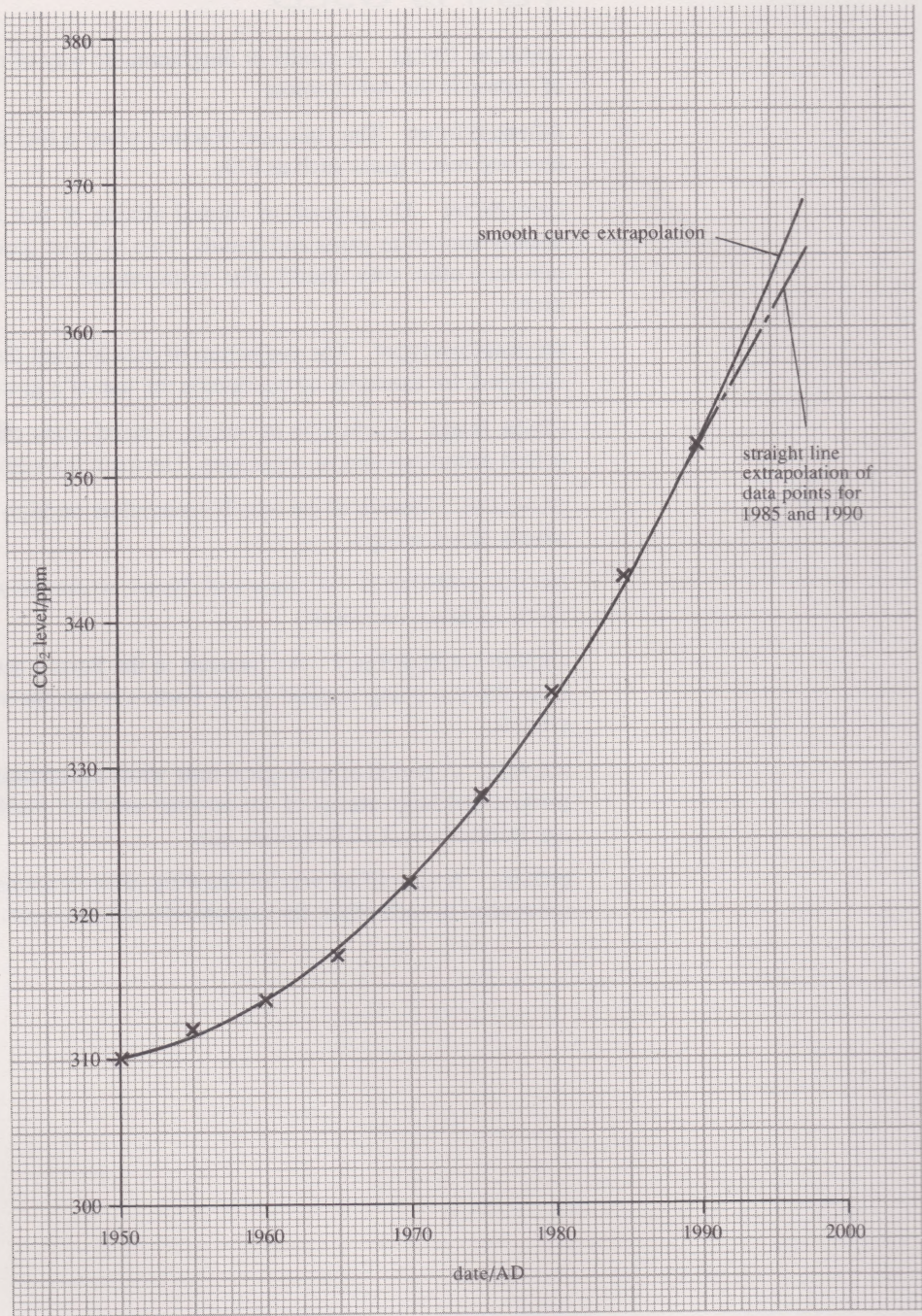
APPENDIX 2

Figure 11   Completed Figure 4. The graph up to 1990 can be most easily drawn by first connecting adjacent data points with a straight line. Each section of the graph is slightly steeper than the previous section. Finally, if there are any 'kinks' in the graph, the straight lines can be changed to a single smooth curve.

SAQ ANSWERS AND COMMENTS

SAQ 1 This is best done in several steps: first we need to calculate how much carbon is present in a tonne of coal:

From Table 1, this coal contains 85% of carbon, so one tonne of coal will contain: $1 \times 85/100 = 0.85$ tonnes of carbon.

We know (from Equation 1) that 12 tonnes of carbon will combine with oxygen on burning to form 44 tonnes of CO_2, so 0.85 tonne of carbon will form:

$0.85 \times 44/12 = 3.12$ tonnes of CO_2 (to two decimal places)

SAQ 2 60 million tonnes of coal with an average carbon content of 75%, will contain $60 \times 75/100 = 45$ million tonnes or 45×10^6 tonnes of of carbon.

We know that 12 tonnes of carbon burn to give 44 tonnes of CO_2 (see Equation 1).

Therefore 45×10^6 tonnes of carbon will give:

$$45 \times 10^6 \times 44/12 = 165 \times 10^6 \text{ tonnes of } CO_2$$

That is 165 million tonnes of carbon dioxide, or about three tonnes for everyone in the country!

SAQ 3 Temperature change for the present day (1990 AD) = 0.0 °C

Temperature change for 2100 AD = +4 °C

Therefore, rate of increase = $4/110 = 0.036$ °C per year

So the comparative rates of heating are: $0.036/0.005 = 7.2$

So heating up of the climate is estimated to be 7 times as fast for the next century as at the start of the so called medieval warm period.

SAQ 4 It seems that burning of fossil fuels adds about 5 billion tonnes of carbon as CO_2 to the atmosphere each year, and forest fires about another 2 billion (Figure 7).

Therefore the total amount of CO_2 added to the atmosphere from these activities each year will be:

$$7 \times 10^9 \times 44/12 = 25.67 \text{ billion tonnes of } CO_2 \text{ per year}$$

SAQ 5 The actual amounts of CO_2 added to the atmosphere each year by fossil fuel burning and forest fires are about twice as much as the increase of CO_2 in the atmosphere each year. The burning of fossil fuels alone is 5/7ths of this CO_2, plenty to account for the observed rise in CO_2 in the atmosphere.

SAQ 6 We cannot give a definite answer but you should have noted the following. It is likely that increased levels of CO_2 in the atmosphere will cause some global warming, due to the so called 'greenhouse effect'. Best estimates are that global temperatures will rise by about 4 °C by the year 2100 AD.

SAQ 7

(a) Volume of petrol used: $25\,000/10 = 2\,500$ litres

mass of petrol used: $2\,500 \times 0.8 = 2\,000$ kg = 2.0 tonnes.

(b) Mass of carbon in petrol: $2.0 \times 0.8 = 1.6$ tonnes

mass of CO_2 produced: $1.6 \times 44/12 = 5.87$ tonnes.

SAQ 8 Fuel required (from SAQ 7(a) answer = 2 500 litres)

$\dfrac{2\,500}{4.5}$ gallons which = 556 gallons.

To find out the number of drums we need to divide by the number of gallons each drum holds:

$\dfrac{556}{44}$ drums = 12.63 drums.

So you would have to order 13 drums.

SAQ 9 Internal area of ground floor of house:

$$= 9 \times 5 = 45 \, m^2$$

Internal volume enclosed by the walls = $45 \times 5 = 225 \, m^3$

The area of the gable end of a roof is given by the area of the two right angled triangles of which it is made up, see Figure 20, Module 3.

The area of a right-angled triangle is $\frac{1}{2} \times$ height $\times$ width,

so area of two triangles = height $\times$ width,

Height of triangle = 2 m

Base of triangle = $\dfrac{5}{2}$ m

So area of gable end = $2 \times \dfrac{5}{2} \, m^2$

To find the volume of the roof space multiply this area by the length:

$$5 \, m^2 \times 9 \, m = 45 \, m^3$$

Therefore total internal volume of house = $270 \, m^3$

To find the volume of CO_2 produced in exhaust fumes use the formula:

$$\text{Volume} = \frac{\text{mass}}{\text{density}}$$

Amount of CO_2 produced in a year is 5.87 tonnes

Or, $5.87 \times 1000 = 5\,870$ kg

Density of CO_2 is $2 \, kg \, m^{-3}$

Therefore, volume of $CO_2 = \dfrac{5\,870}{2} \, m^3 = 2935 \, m^3$

To see how many house-fulls of CO_2 is produced, divide the volume of CO_2 produced by the volume of the house.

$$= 2\,935/270 = 10.87 \text{ house-fulls}$$

In a year your car emits about 11 house-fulls of CO_2.